Land Management Report 3

Factors Contributing to Blowdown in Streamside Leave Strips on Vancouver Island

by M. K. Moore

Province of
British Columbia

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ABSTRACT

Blowdown is a complex natural phenomenon and is caused by the simultaneous interaction of a number of natural factors. Streamside leave strips of varying ages and vegetational compositions were observed in 59 watersheds on Vancouver Island. Some leave strips had sustained extensive blowdown; others had sustained little or no blowdown. Observations were made to determine the factors which caused blowdown or contributed to windfirmness in these leave strips. These observations were compared to the findings of blowdown studies in other areas.

It is concluded that with an understanding of the factors that contribute to blowdown and an evaluation of the conditions that exist on a given site, a relative assessment of the likelihood of blowdown can be made. A summary of the factors which were observed to contribute to blowdown on Vancouver Island is included.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
LIST OF FIGURES	v
LIST OF PLATES	v
INTRODUCTION	1
QUALIFYING COMMENTS	3
FACTORS CONTRIBUTING TO BLOWDOWN	9
1. Meteorological Factors	9
a. Winds	9
b. Precipitation	14
2. Physical Location and Topographical Factors	14
a. Geographical Location	14
b. Local Topography	17
3. Site Factors	19
a. Bedrock	19
b. Soil	20
c. Tree Species	21
4. Other Factors	24
ASSESSMENT OF BLOWDOWN POTENTIAL	25
SUMMARY	27
BIBLIOGRAPHY	30

LIST OF FIGURES

Figure 1. Location of streamside leave strips and blowdown observed on Vancouver Island..... 8

Figure 2. Winds accelerate as they flow over obstructions or through constrictions.....11

Figure 3. Wind speed is lower below frictional boundary than above because of greater friction.....12

Figure 4. Wind turbulence on the windward boundary as winds enter a clearcut.....13

Figure 5. Map of Vancouver Island showing location of coastal plains.....16

Figure 6. Leave strips in draws appear windfirm if running parallel to the wind.....18

Figure 7. Leave strips at the bottom of steep slopes appear to be windfirm.....18

Figure 8. A diagram showing the critical soil factors leading to blowdown on Vancouver Island streamsides.....22

LIST OF PLATES

Plate 1. Extensive blowdown has occurred in some streamside leave strips..... 2

Plate 2. A number of streamside leave strips have stood for several years with little blowdown..... 4

INTRODUCTION

Narrow strips of vegetation, commonly referred to as leave strips or fringe strips are now often left along streams in order to protect them from some of the impacts of forest harvesting. In coastal British Columbia these leave strips are intended to be comprised primarily of immature trees, deciduous trees, snags, and understory shrubbery (13) but often, for various reasons, large mature coniferous trees are also reserved from harvesting.

Several reasons are usually cited for leaving these strips (15,39). They provide shade and a supply of leaves and needles for the stream, protect it against the entry of logging debris, preserve the stability of its banks and provide cover and a supply of insects for fish inhabiting the stream.

Trees and minor vegetation along the bank also provide habitat for wildlife and bird species associated with the stream and can enhance the experience of fishermen and other recreationists. They are regarded as providing, in part, for the multiple use of the forest resource.

However, a number of the leave strips left along streams on Vancouver Island have suffered extensive wind damage and the argument is often expressed that leaving exposed trees standing along streams is impractical and unwise because of this blowdown problem (45,61). Blown down trees are expensive and dangerous to harvest and often cannot be retrieved economically. It is argued that the upturned roots are a source of stream sedimentation and that branches, tops and trunks of blown down trees are traps which lead to debris jams. These jams divert the stream and move sediment, gravel and debris downstream. In addition blown down leave strips are of little value and are sometimes even dangerous to wildlife species and recreationists.

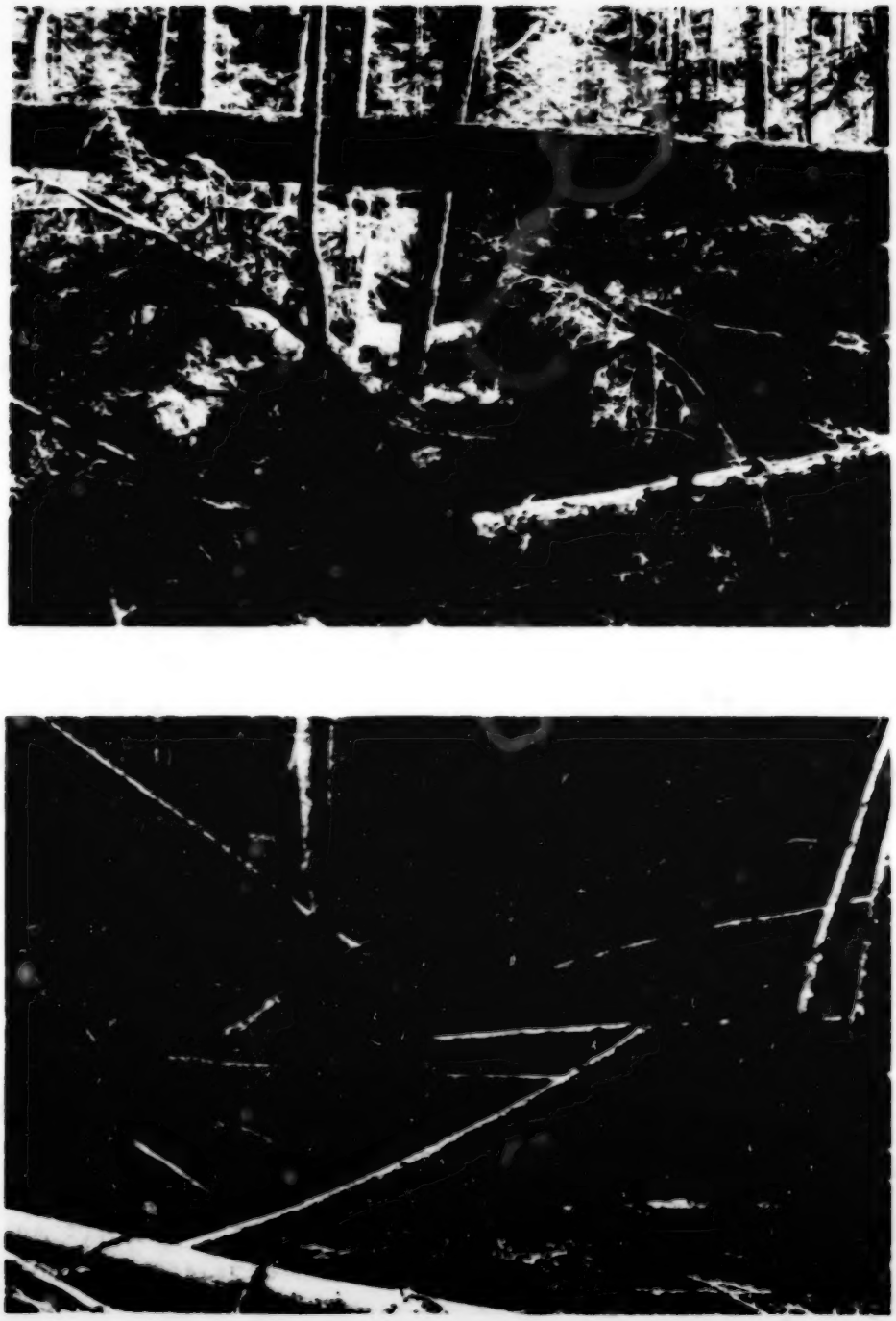

Plate 1. Extensive blowdown has occurred in some streamside leave strips.

This report presents some observations on the causes and extent of blowdown in leave strips on Vancouver Island based on fieldwork conducted in 1974 [1] and 1975. These observations are compared to findings from other studies in Western North America and elsewhere. A number of suggestions are made on evaluating the likelihood of blowdown on a given site and minimizing its occurrence.

Before proceeding to discuss these causes of blowdown, however, it is important to make some initial qualifying comments.

Qualifying Comments

First, considerable blowdown in leave strips has occurred on a number of streams in widely separated localities on Vancouver Island. However, there are also leave strips on a number of widely separated streams that have stood exposed to the wind for several years with little or no blowdown. It is not true to state that all leave strips have blown down. It appears that, under the right set of environmental conditions, leave strips along streams will be reasonably windfirm.

Second, blowdown of trees in a leave strip is not necessarily a harmful or undesirable occurrence. Blowdown is a natural forest process and many forest streams have tremendous volumes of logs and large woody debris in them naturally (27,57,58). Most of this debris enters from blowdown during windstorms and is very important in maintaining the stability and productivity of stream systems.

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[1] Detailed illustrated reports on blowdown in leave strips in 8 areas on Vancouver Island are on file with the Fish and Wildlife Branch in Nanaimo. A summary report is also on file--Moore, K. and B. MacDonald, 1974. Final Report of the Fringe Strip Study Team. 19 pages.

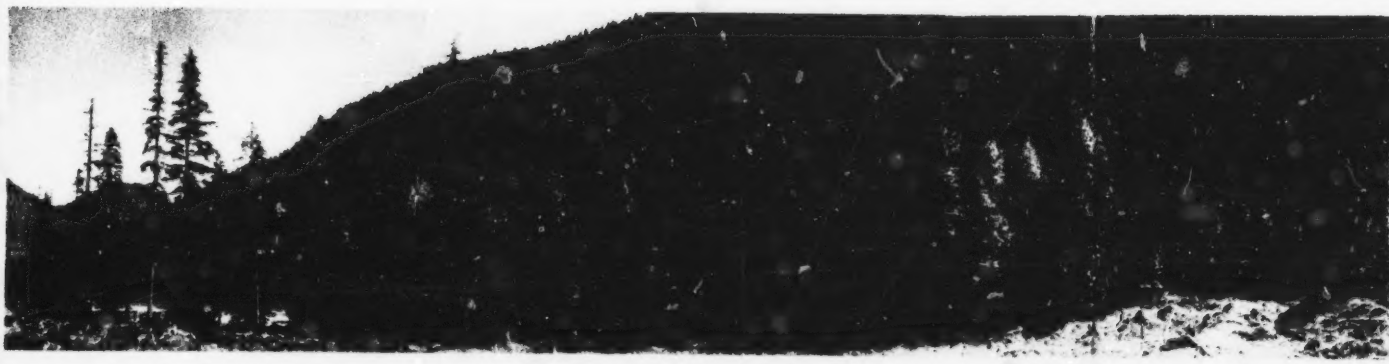

Plate 2. A number of streamside leave strips have stood for several years with little blowdown.

In small streams the blown down natural debris lodges in the stream channel and remains in place for a long period of time (58). It accumulates gravel and creates pools which serve to dissipate stream energy and slow the movement of materials through the stream system (58). The stepped profile of pools and riffles or small falls which develops is a result of the accumulation of blown down debris and is particularly important in maintaining the stream stability and preventing the stream from becoming an unproductive sluice box (33). The pools which are created by blown down debris, and the debris itself, provide habitat for numerous organisms and are the source of much of the biological productivity of the streams (54).

In fish bearing streams, large debris and debris accumulations play an important role in creating desirable habitat for fish (31). They create the pools and back eddies and hiding and resting places that are generally desirable components of rearing areas for salmon and trout. Both young and adult salmon are often found associated with debris accumulations and overwintering coho and steelhead fry are most commonly found associated with upturned root wads and logs (17,32). Large debris in the stream plays an important role in maintaining these fish populations.

Thus blowdown of trees into the stream is a natural occurrence and a continuing input is necessary for the maintenance of the stability and productivity of the stream system. Researchers in Oregon and Colorado (33,54,58) have suggested that leave strips along streamsides can be regarded as future sources of large debris for the stream system and should be left along streams in the expectation that over time they will blow down.

Obviously this argument applies to the blowdown of a few isolated trees in a leave strip over a period of time, which has been the case in some leave strips on Vancouver Island. It is certainly true that extensive blowdown occurring at one time may be detrimental to the stream. It is simply

"too much of a good thing" and it is to the avoidance of this large scale blowdown that this report is directed.

Third, blowdown on different streamsides is not all equally detrimental to the stream. The impact depends primarily on topography, the shape of the stream edge, the size and gradient of the stream and, as discussed earlier, the extent of the blowdown.

Blowdown of trees on steep streamsides, for example, appears to create serious problems. The upturned roots create considerable disturbance on the slope and the trees all tend to collect in the stream channel. This can lead to slope failures into the stream or to debris torrents down the stream and the resulting sedimentation and scouring of the stream channel usually has serious consequences. On the other hand, trees which blow down on flat streamsides where the stream channel is well defined, often fall directly across the stream channel and have little or no effect on the stream. In the long run this blowdown may actually be beneficial.

On large streams, blowdown can have serious impacts because the stream has sufficient energy to move large debris and create debris jams behind the blowdown or downstream from it. Large streams also have the energy to erode and undercut stream banks when water is forced around blown down trees and root wads. This can lead to more trees falling into the stream. It can also force the stream to cut a new channel around the blowdown or debris jam and result in the movement of a great deal of material. Small streams have sufficient energy to move branches and limbs and this too can cause debris jams behind existing natural debris. However many small or low gradient streams do not have the capacity to move large debris into debris jams or the energy to do serious bank erosion, and the impact of blowdown is less severe. <u>It is therefore important when considering the likelihood of blowdown to consider also the severity of the potential impacts</u>. Areas have been observed where it is felt that blowdown has had less impact on the stream than logging to the stream edge.

Fourth, the findings presented in this report are the result of two summers of fieldwork on Vancouver Island (See Figure 1) and an extensive review of literature pertaining to blowdown (see bibliography). The fieldwork concentrated on blowdown in streamside leave strips and therefore the report does not cover blowdown occurring on the perimeters of cutblocks. And since all the fieldwork was in coastal forests, the only timber types covered are Douglas fir, Douglas fir-western hemlock, western hemlock-amabilis fir, Sitka spruce-western hemlock and western red cedar-western hemlock. The report does not deal with any interior types.

Most of the streamside wind damage on Vancouver Island is blowdown, which is defined as trees uprooted by the wind (40). Relatively little windbreak, which is defined as trees snapped off by the wind, (40) has been observed. Thus this report deals with blowdown and not windbreak.

Blowdown is a very complicated problem. It is not simply the result of high winds but is caused by the simultaneous interaction of a number of natural factors including location, local topography, climate, aspect and slope, soil depth and texture, tree species and rooting characteristics and stream characteristics. The particular combination of these natural factors causing blowdown in any location will vary widely and can be affected by the shape of the logged opening and by the care exercised during and after logging. Thus it is extremely difficult if not impossible to predict with certainty that, for a particular site, a particular combination of conditions will occur and blowdown will result. Nevertheless, an understanding of the conditions which have been observed on Vancouver Island and which do contribute to blowdown will allow a <u>relative</u> assessment of the likelihood of blowdown on any streamside site and will aid in the decision as to whether a leave strip can be left. These conditions are grouped under a number of headings and subheadings in this report but in assessing an area for blowdown they have to be considered as a whole.

1. Stranby R.
2. San Josef R.
3. Kwatleo R.
4. Koprino R.
5. Nahwitti R.
6. Pugh Cr.
7. Mahatta R.
8. Johnstone Cr.
9. Waukwaas Cr.
10. Keogh R.
11. Kilpalla R.
12. Bonanza Cr.
13. Kaouk R.
14. Rowland Cr.
15. Kapoose Cr.
16. Porritt Cr.
17. Tatchu Cr.
18. Zeballos R.
19. Nimpkish R.
20. Siebelhall R.
21. Kla-anch R.
22. Sucwoa R.
23. Canton Cr.
24. Conuma Cr.
25. Oktwanch R.
26. Muchalet R.
27. Gold R.
28. McCurdy Cr.
29. Sylvia Cr.
30. Heber R.
31. Eve R.
32. Adam R.
33. White R.
34. Moakwa Cr.
35. Salmon R.
36. Cypre R.
37. Indian R.
38. Staghorn Cr.
39. Coos Cr.
40. Cook Cr.
41. McTush Cr.
42. Cameron R.
43. Carnation Cr.
44. Pachena R.
45. Nitnat R.
46. Jump Cr.
47. Nanaimo R.
48. Chemainus R.
49. Koksilah R.
50. Muir Cr.
51. Benson R.
52. Palmerston Cr.
53. Tlatlos Cr.
54. Kunnum Cr.
55. Newcastle Cr.
56. Perry Cr.
57. Twaddle Cr.
58. Tlupana R.
59. Ucona R.

Figure 1. Location of streamside leave strips and blowdown observed on Vancouver Island.

FACTORS CONTRIBUTING TO BLOWDOWN

Four main groups of factors have been identified as contributing to blowdown: 1. Meteorological factors; 2. Physical location and topographical factors; 3. Site factors; and 4. Other factors. These are now discussed individually.

1. Meteorological Factors

a) Winds

The most obvious and immediate cause of blowdown is wind. On Vancouver Island the most severe winds, and the vast majority of blowdown, occur during the months from October to March. The winds that cause this blowdown are storm winds, rather than prevailing winds, and they blow predominantly from the south-east and, to a lesser extent, from the south and south-west. Their importance in causing blowdown in leave strips is readily observed in leave strips on Vancouver Island. A great deal of the blowdown is either blown down in a northerly direction or is in leave strips which have been exposed to the south. Storm winds from a southerly direction during the period from October to March have also caused the vast majority of blowdown studied in coastal B.C., Alaska, Washington and Oregon (10,12,30, 45,49,50,51,56).

One exception to the general principal of southerly storm winds causing blowdown may be the occurrence of strong north-easterly winds out of mainland coastal inlets causing blowdown on the north-east corner of Vancouver Island. These winds have caused blowdown in Alaska and are called "Bora" winds (51).

The facts relating to the seasonality and direction of winds causing blowdown are reasonably well documented. A third important factor, the speed of winds, is not known but it has been observed that most blowdown occurs during normal winter wind storms, often the first winter storms. Blowdown is more a result of trees which were long protected from the full force of wind, suddenly being exposed, than

of excessively strong or freak winds. However, numerous factors influence the speed and force with which winds strike a leave strip and predispose particular strips to blow down while others remain windfirm. It is important, therefore, that the physical factors associated with the movement of winds are understood.

Wind is fluid; it flows like a stream over a surface, around corners and over obstructions. Storm winds on Vancouver Island tend to come from a southerly direction, but like a stream they will follow a valley like a channel and change direction away from the original one. The wind direction is altered by topography (3,6,29,36,37,43,60).

Like a stream, wind speeds up as it goes through a constriction or a narrowing in its path. It also becomes turbulent as it flows out of a constriction or as it flows over an obstacle (3,6,30,43,45) (See Figure 2).

Wind is slowed by friction (6,14,24,29,47,60) Over a forest, friction is provided by the canopy and the wind speeds in the canopy and immediately above it are lower than those some distance above the canopy. The highest speeds are recorded some distance above the canopy, above an imaginary line called the frictional boundary, where the frictional effect of the canopy is lost (24,47). When the forest is cut, the frictional boundary is lowered and the highest wind speeds are found much closer to the ground. Thus trees left in a leave strip are not only suddenly exposed to wind, but are also exposed to winds of higher velocities (See Figure 3). In addition the wind will speed up through a clearcut because the frictional resistance of the ground is less than that of a forest canopy (24,60). The frictional resistance over water is even less and high wind speeds are common at the end of lakes.

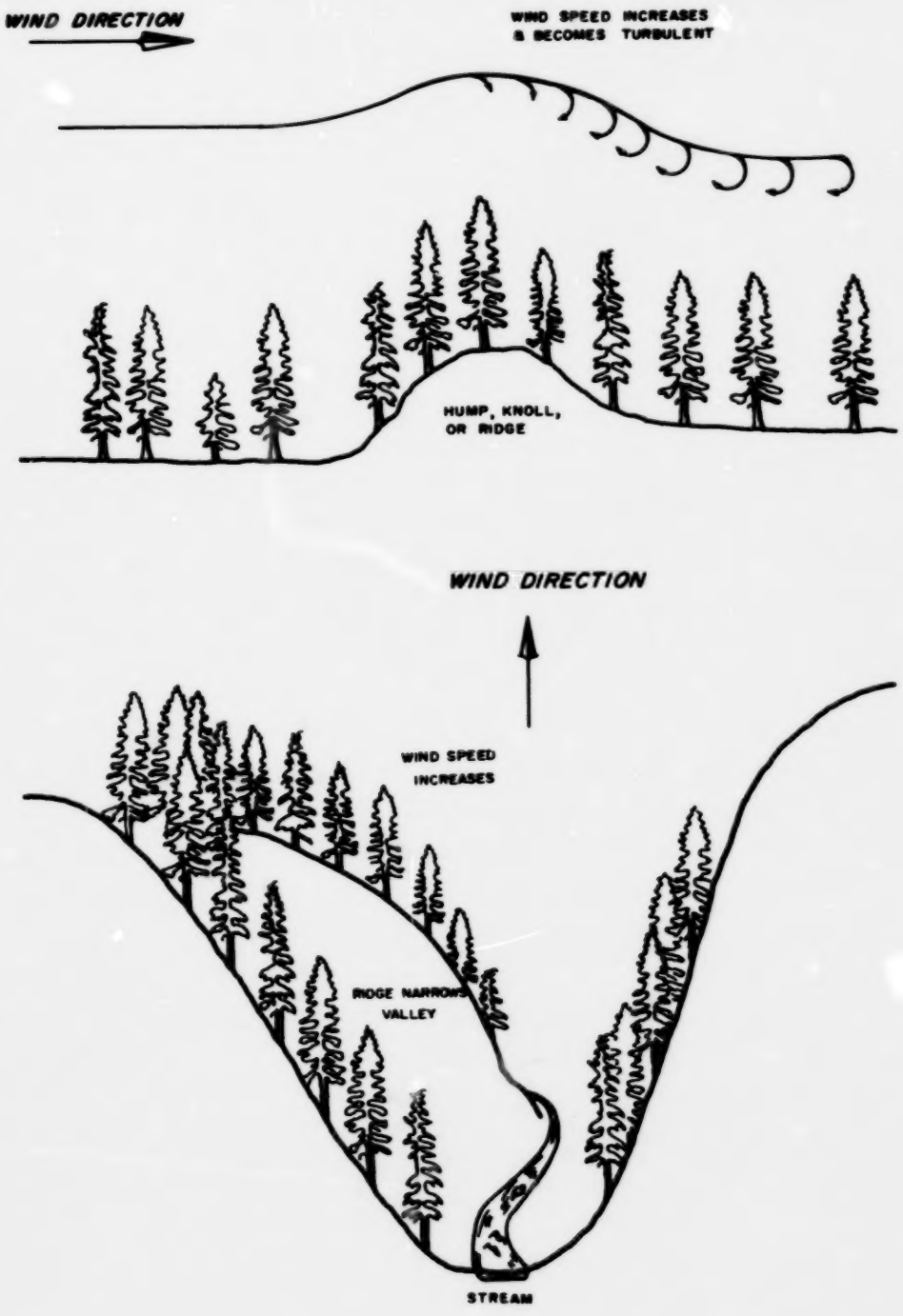

Figure 2. Winds accelerate as they flow over obstructions or through constrictions. They also become more turbulent.

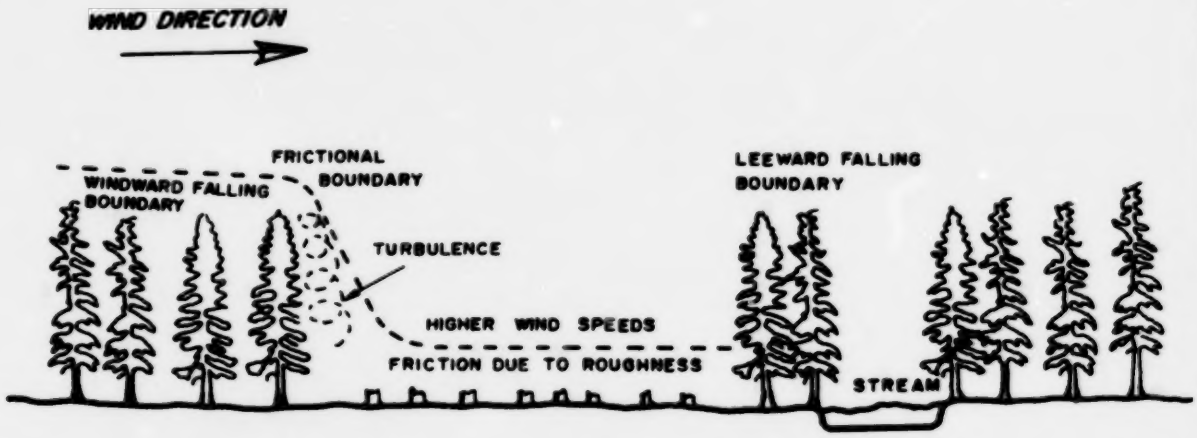

Figure 3. Wind speed is lower below frictional boundary than above because of greater friction. After logging higher wind speeds hit exposed trees.

Wind speeds increase as winds pass through narrow valleys, through saddles or over ridges because of the basic principle of physics that any moving fluid speeds up as it passes through a constricted space. This topographical acceleration of wind is an important factor in blowdown and will be discussed further under "Local Topography."

Winds also become turbulent as they flow out of narrow valleys or over ridges and knolls in the same way that smooth water flowing over a log or rock becomes turbulent (1,6,14,30,36). On a smaller scale the same effect occurs as winds flowing over a canopy suddenly drop into a logged opening. They become turbulent and can cause trees along the windward cutting boundary[2] to sway and blow down (See Figure 4).

[2] The cutting boundary over which winds enter a clearcut is the windward boundary. The boundary over which winds leave a clearc is the leeward boundary. Generally, most blowdown occurs on the leeward boundary but turbulence does cause blowdown to occur on the windward boundary.

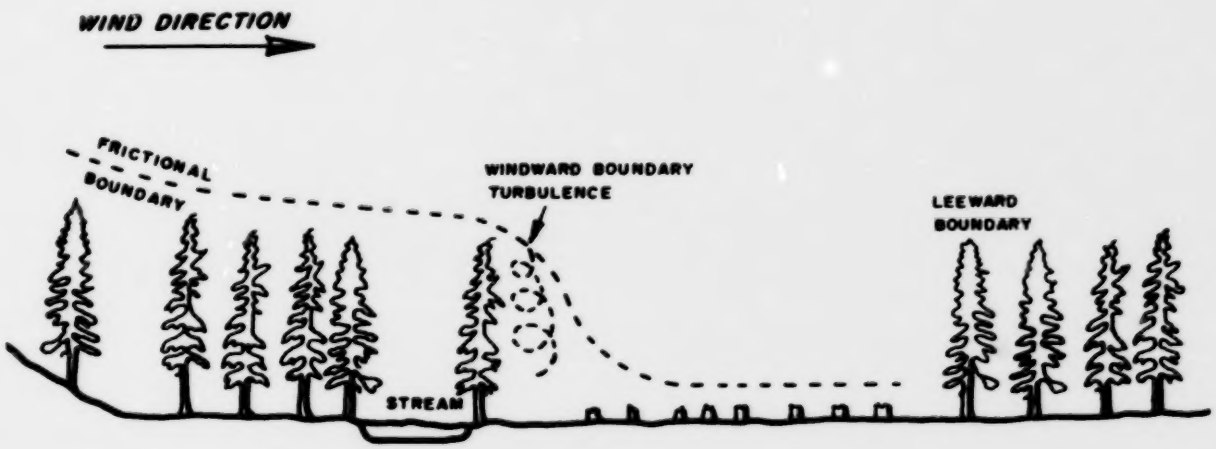

Figure 4. Wind turbulence on the windward boundary as winds enter a clearcut. Windward boundaries are generally more windfirm than leeward boundaries. Trees blowing down on this boundary may fall into the wind.

These four concepts of i) winds being channelled by topography, ii) the frictional boundary, iii) increased speed due to constriction, and iv) turbulence, are important to much of the following discussion on blowdown.

In general, leave strips exposed to southeasterly, south or southwesterly storm winds are more likely to blow down but this exposure must be considered against many other factors. Leave strips exposed to topographically accelerated or turbulent winds are also likely to blow down.

b) Precipitation

The most serious high winds tend to be fall or winter winds and the fall and winter precipitation has an additional effect on the windfirmness of a leave strip. Heavy rainfalls, particularly during fall and winter, saturate soils and reduce the holding strength of the soil and root wad of trees. Thus the simultaneous occurrence of high rainfall and exposure to winter storm winds from the south, south-west or south-east is a major cause of blowdown in streamside leave strips. This has also been reported in many other studies (6,10,12,35,45,50).

A winter snowfall, however, seems to have a stabilizing effect and very little streamside blowdown has been observed in areas that receive prolonged snow in the winter. Studies in other areas have found that under snow the soil moisture content is low, and the soils may even be frozen, thus creating greater strength in the root wad. By the time the snow melts and creates high soil moisture conditions and reduced root strength, the period of winter storm winds has passed (6,7,18).

Thus a high winter rainfall indicates a high probability of blowdown; a prolonged duration of snow in the winter indicates a lower probability. Other factors also contribute to this as high rainfall areas are generally at lower elevations and generally more exposed to storm winds. Areas with winter snowfall tend to be higher and farther from the ocean and are often sheltered from the severe storm winds.

2. Physical Location and Topographical Factors

a) Geographical Location

The geographical location of a leave strip is important because of the inter-relationships between location and the factors of exposure to high winds and high rainfall discussed above. In general the blowdown problem appears to be most serious on the west coast and north coast of Vancouver Island because these are the areas of the most severe storm winds and the highest rainfalls. Much less blowdown in leave strips has been observed on the east coast and centre of Vancouver Island.

More specifically, the worst blowdown occurs on the west and north coasts along long narrow inlets that open to the south and southeast and on flat coastal plains exposed to the south and southeast. Much less blowdown in leave strips occurs along inlets that open to the west. This is because winds follow valleys and it appears that the direction that coastal inlets open determines their exposure to winds. The same principle holds true for the interior valleys of the Island although, in general, they are more windfirm than coastal inlets or coastal plains. Major drainages that drain south or north or southeast or northwest appear to have more blowdown associated with them than drainages which run east or west.

On the flat coastal plains, known as the Estevan coastal plain and the Nahwitti lowlands, the blowdown is primarily a result of the exposure to severe storm winds (See Figure 5). Heavy blowdown on coastal plains is also reported in other studies (12,16).

Leave strips along streams at the end of large lakes are prone to blowdown because of the high wind speeds over the lake. Some examples of this have been observed on Vancouver Island and are reported elsewhere (37).

The orientation and aspect of a leave strip in relation to the direction of the wind is also important. Leave strips which run parallel to the direction of the main valley are usually parallel to the wind, and generally windfirm. Blowdown tends to occur at points where the stream turns abruptly across the valley or on tributary creeks which flow at right angles to the main stem of the stream. In these cases the leave strip is perpendicular to the wind and much more exposed. The local topography, discussed below, can also cause wind to change direction. The orientation of leave strips at right angles to wind is a major cause of blowdown and has been cited in many studies (3,4,10,30,37,45,50,56).

Figure 5. Map of Vancouver Island showing location of coastal plains. (Source, Holland S.S., 1976).

b) Local Topography

Local topography is a very important factor contributing to blowdown in leave strips because of its effect in accelerating winds and causing them to become turbulent. Small humps, knolls or rock outcrops, often only seventy metres high, in the middle of a clearcut appear to be enough of an obstruction to force wind to go over them or around them. They constrict the flow of wind and cause it to accelerate and become more turbulent. Numerous blowdown sites on Vancouver Island were found to be associated with these small knolls or humps.

Ridges or shoulders entering the main valley act to constrict the flow of wind, causing it to speed up and become turbulent on the lee side. Blowdown in leave strips along a stream immediately downwind of these shoulders or ridges was also observed on Vancouver Island. The effect of local topography on wind causing blowdown is reported in many other studies (4,6,29,30,36,37,38,43,45,46,50,56).

The slope of a streamside appears to have some influence on whether or not a leave strip is windfirm. Strips in deep draws or over topographic breaks appear to be quite windfirm particularly if they are running parallel to the main valley (See Figure 6). Leave strips in flat streamside areas appear to have sustained more blowdown than those on slopes.

If a deep draw is running across the wind, blowdown of trees is often observed along the top of the break into the draw. However, if the slope is long and steep (greater than 70%) it is possible that a strip of trees along the bottom of the draw will be windfirm (See Figure 7). Studies in other areas have indicated that while wind will follow a relatively gentle slope, it breaks away from a steeper slope. The figures given for this vary considerably but most research indicates that slopes greater than 50 to 70% will be windfirm (4,6,18,37,45,50). In these cases the slope is offering topographic protection and this partially explains why there is little blowdown in the narrow interior valleys of Vancouver Island which run roughly east to west or southwest to northeast.

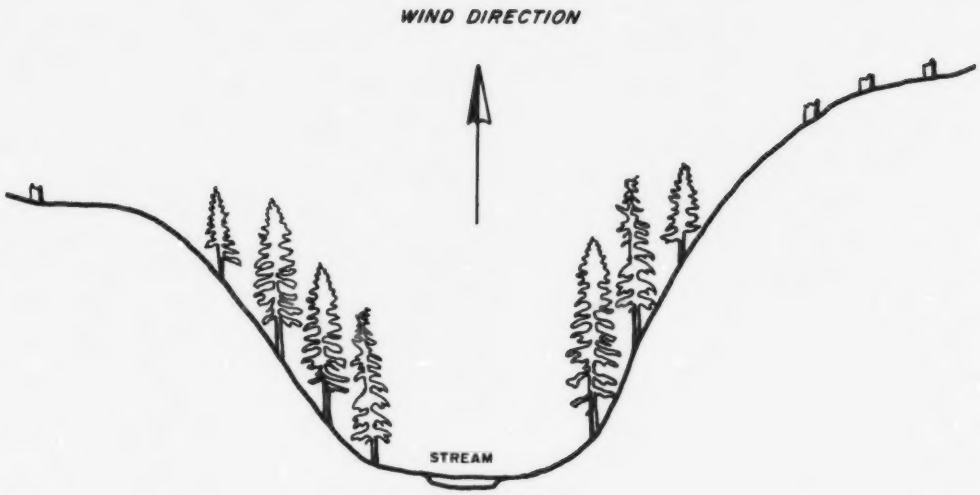

Figure 6. Leave strips in draws appear windfirm if running parallel to the wind.

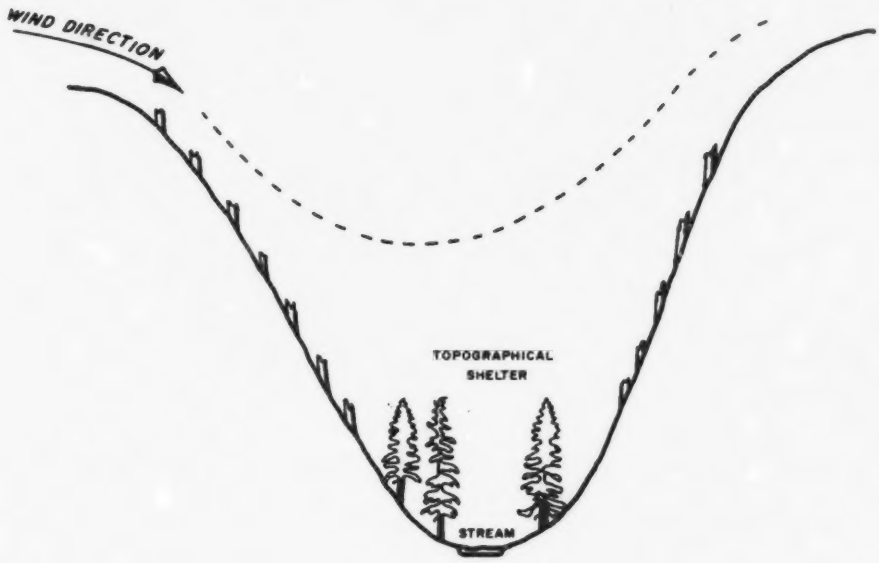

Figure 7. Leave strips at the bottom of steep slopes appear to be windfirm. However if excessively steep, slope stability problems may negate the value of the leave strip.

One final topographic factor that contributes to blowdown is the microtopography under the forest stand. Blowdown is often found on flat areas associated with a hummocky, mound and pit micro relief. The small depressions and mounds are a result of old blowdowns where roots have upturned and rotted leaving a hummocky appearance on the ground. Often skunk cabbage, sphagnum moss, liverworts and other wet site plants are present in the depressions. This type of micro relief indicates shallow rooting of trees, and heavy blowdown in leave strips has been found associated with it on Vancouver Island and in other areas (45,57).

3. Site Factors

a) Bedrock

Bedrock underlying shallow soils is an important site factor affecting the rooting characteristics and the rooting depth of trees. If the bedrock is fractured, tree roots will penetrate the fractures and a windfirm leave strip is usually observed. This is particularly true on Vancouver Island for Douglas fir on rocky sites with bedrock outcrops. Tree roots penetrate cracks in the rock and are windfirm. Similar observations have been made in other studies (6,23,45,56).

If the bedrock is smooth, massive and unfractured, tree roots perch on the top and around the rock. When exposed to wind after logging, these trees blow down. The blowdown either occurs immediately because there is insufficient strength in the root system to withstand wind or it occurs as a result of increased sway in the tree which severs the root system over time. In the United States this is referred to as the "shaving brush effect" and the roots of blown down trees have a frayed appearance (51).

b) Soil

Soil characteristics have been recognized by virtually all researchers as some of the most important factors contributing to blowdown (4,5,16,21,25,26,30,44,46,50). Soil depth, texture, cohesion and drainage are all important because of their direct impact upon the rooting depth and rooting strength of trees. To some extent these factors are inter-related.

It is often stated in the literature that deep soils are more windfirm than shallow soils or that shallow soils of greater than a certain depth, say 50 centimetres, have been found to be windfirm (3,4,7,30,37,38). However, observations on Vancouver Island indicate that while this may be true in general, effective rooting depth is usually more important than soil depth. Shallo soils (less than 50 cm.) generally lead to shallow and relatively weak root systems and blowdown has been observed on Vancouver Island associated with this condition. However, as discussed earlier, shallow soils over fractured bedrock often support windfirm leave strips.

Considerable blowdown has also been observed on deep soils on which the effective rooting depth is limited by the presence of cemented layers, clay layers, layers of gravel, or other layers which are impermeable to roots, create perched water tables or are very low in nutrients or moisture. This situation leads to the development of plate or disc root systems and is often found associated with blowdown (4,6,21,22,45,50).

In general, then, deep soils are more windfirm than shallow soils but factors which either limit or increase the effective rooting depth must also be considered.

Soil texture is another important factor because of its effect on drainage and effective rooting depth. Some of the literature suggests that on coarse textured soils, rooting depths will be greater and trees more windfirm (5,35,37,44). On fine textured soils, roots will be shallower and trees more prone to blowdown. This is generally supported by

observations on Vancouver Island but is again rather over-simplified. Cohesion is also an important factor. On Vancouver Island, blowdown has often been observed on fine textured clay and silt soils because these soils do not support deep root systems and because they have very low cohesive strength when saturated during the winter. Blowdown has also been observed on coarse textured alluvial soils, which may have deep roots but which also have very low cohesive strength. The medium textured soils, which lead to deep rooting, appear to be the most windfirm.

Drainage reflects soil texture and effective rooting depth and is a useful indicator of blowdown. Poorly drained soils indicate a shallow root system usually as a result of fine textured soil or the presence of an impermeable or cemented layer in the soil. The flat disc shaped root systems developed by trees on these sites can often be observed on blowdown. Organic soils and swampy areas, however, are often quite windfirm because the trees are small and open grown and the soil absorbs movement during winds.

Well drained soils encourage deeper, larger root systems and are usually observed to be more windfirm. However, rapidly or excessively drained soils over unfractured bedrock have contributed to blowdown.

Soil factors which influence blowdown are inter-related. Basically any factors which act to inhibit the development of deep roots or create shallow plate root systems will contribute to blowdown. Figure 8 illustrates the interaction of these factors.

c) Tree Species

Tree species influence blowdown primarily because of their rooting characteristics and to a lesser degree the shape of their crown. Observations on Vancouver Island have definitely indicated that some species are more likely to blow down than others and based on these observations, and a review of studies elsewhere, it is possible to rank tree

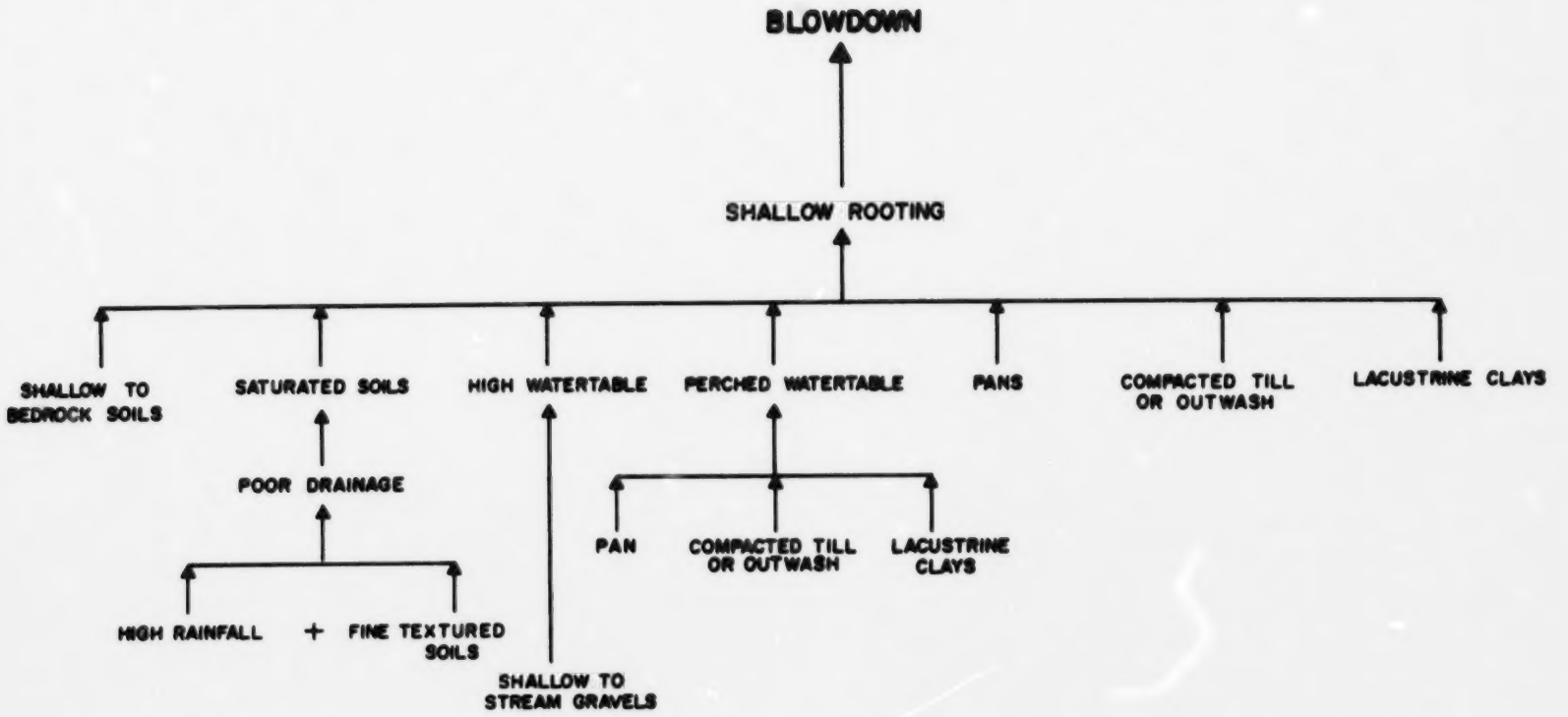

Figure 8. A diagram showing the critical soil factors leading to blowdown on Vancouver Island streamsides. (Source, Bowling C., 1976)

species according to their windfirmness (12,20,22,23,25,30, 45,50). It should be kept in mind that tree species reflect many of the characteristics of the site they grow on. Thus many of the observations pertaining to rainfall, geographical location, soil texture, drainage, and so on are reiterated here. Those species, for example, which grow on coarse textured, well drained soils in low rainfall areas develop deep root systems and are relatively windfirm.

Douglas fir and grand fir appear to be the most windfirm tree species. These trees generally grow on well drained sites and develop deeper root systems than other species. Even on shallow soils they develop extensive, heavy, root systems and penetrate fractured bedrock. On Vancouver Island little streamside blowdown of Douglas fir has been observed and studies elsewhere have found it to be a windfirm species (9,12,50,56).

Western red cedar is also quite windfirm (12,30). It has a very fine root system which develops a large and heavy root ball of soil and roots. In many cases it also develops a very open crown with dead tops and presents little resistance to the flow of wind.

Alder is quite windfirm (50). It has a small crown and in the winter has no leaves, thus offering little resistance to the wind. In addition, it develops a fairly extensive root system relative to the crown.

Sitka spruce is windfirm on some sites but prone to blowdown on others (12,17,18,25,50). On alluvial sites where the soils are well drained and on terraces which sit a metre or more above the stream, spruce will develop a very large, deep root system. Numerous examples have been observed on Vancouver Island where other tree species have blown down while spruce remain standing. However on sites where drainage and root penetration is impeded by compacted or cemented layers, fine textured soils or stream gravels, or a high water table, spruce develops a very large, flat disc shaped root system and is very prone to blowdown when winter rains saturate the soils.

Western hemlock and amabilis fir are the least windfirm species with hemlock appearing to be slightly more windfirm than amabilis fir (9,12,30,50,56). However, the vast majority of blowdown on Vancouver Island has occurred in hemlock and amabilis fir and it appears that on sites where these trees are exposed to storm winds they will blow down. The only exceptions to this may be very open grown stands where the trees have a large crown and have been exposed to strong winds in the unlogged forest or on well drained alluvial areas where the trees develop deep root systems.

Many other studies have attempted to find relationships between age, height, and diameters of trees and blowdown (9,10,20,30,44,50). However, observations in the old growth forests of Vancouver Island indicate these factors have little influence on blowdown and are of little use as indicators.

Open grown trees appear to be more windfirm than those in a very dense stand because of their greater exposure to wind in the unlogged forests. Very large dominant trees and trees in stands with a rough, broken canopy also appear to be relatively windfirm.

4. Other Factors

Numerous other factors have been observed on Vancouver Island or reported elsewhere which contribute to blowdown. If the stream banks are being undercut by the stream in the unlogged forest, it is likely that trees left along the edge will fall down after logging. This has been observed on Vancouver Island and is partly a result of undercutting and partly a result of wind. Blowdown, however, appears to accelerate the process.

Root rot or other decay is reported in several studies as being the most important factor contributing to blowdown (9,22,30,35,45). The reduced root strength can cause extensive blowdown when a leave strip is exposed to the wind. It was not specifically identified on Vancouver Island but is thought to be a likely cause of some streamside blowdown.

Road location along a stream or bridge placement across a stream can contribute to blowdown if it acts to divert the stream and cause bank undercutting. This has been observed on Vancouver Island.

Beaver dams can also contribute to blowdown by flooding leave strip areas and reducing root strengths.

Escaped slash fires in some areas on Vancouver Island damaged the root systems of trees and burned soil organic layers and thus contributed to streamside blowdown (45). Logging damage to leave strip trees from yarding out logs or the operation of equipment is also mentioned in the literature as a cause of blowdown (30,37,38,51,56) and was observed on one area on Vancouver Island.

The size of a clearcut opening is often suggested as a factor which influences the amount of blowdown in a leave strip. However from observations on Vancouver Island it is not possible to find any relationship between blowdown and the size of the logged opening. This lack of a relationship is substantiated by other studies (2,4,30,45,50). In order to prevent winds from dropping into a clearcut, the opening would have to be so small that it would be completely impractical for coastal conditions. All coastal clearcuts are sufficiently large to expose the edge to storm winds and therefore the size of the opening has virtually no influence on whether streamside leave strips blow down.

ASSESSMENT OF BLOWDOWN POTENTIAL

Blowdown results from the complex interaction of a number of factors. Some factors are definitely more important than others but no one alone is a cause of blowdown. Therefore the assessment of blowdown requires consideration of each of the factors outlined above. The decision as to whether or not a leave strip should be left requires consideration of the impact and loss associated with blowdown as well as consideration of the impacts of harvesting.

There are several factors that are indicators of a high probability of blowdown. If there is extensive old blowdown in the area proposed for logging or if there is any evidence of shallow rooting of trees caused by stream gravels, cemented layers, compacted layers, clay, fine textured soils, poor drainage or a high water table the probability of blowdown in a leave strip is high. Shallow rooting can usually be observed along the cutbank of the stream or on upturned root wads in the stand.

Vegetation can serve as a good indication of blowdown likelihood because it is an integrator or an expression of numerous other site characteristics. Observations on Vancouver Island have indicated that there are several species of vegetation associated with blowdown in leave strips. Skunk cabbage is the most obvious one and many times was observed with blowdown (41). It appears that on any site where skunk cabbage is common, blowdown will result (30,50).

Sphagnum moss has also been observed with blowdown, usually in the hummocky micro relief described earlier. Like skunk cabbage, it indicates poor drainage, shallow rooting and a probability of blowdown. On slopes, any indication of seepage water such as black mucky soils and a heavy cover of ferns usually indicates shallow rooting and a likelihood of blowdown.

Topographical features such as knolls, ridges or narrow valleys which funnel winds are also good indicators, as is a hummocky micro relief.

Extensive root rot or other decay in the stand will indicate a high probability of blowdown.

If there are adjacent leave strips in the area or a general absence of blowdown, the length of time since logging can be a useful indicator of the likelihood of blowdown. Studies in other areas indicate that blowdown is most likely to occur within the year after logging and diminishes each year after that. Most studies agree that if blowdown has not occurred five years after logging, the area can be considered windfirm (2,3,4,30,37,45,50). Thus leave strips

which are to be left adjacent to old leave strips, with similar vegetation, soils and topography, can be considered windfirm. Conversely, leave strips proposed for areas where there has been blowdown should not be considered windfirm.

Several factors occurring simultaneously indicate a high probability of blowdown. For example, a proposed leave strip in western hemlock and amabilis fir, on fine textured soils on a coastal plain, oriented in an east to west direction is highly likely to blowdown. Conversely, a proposed strip of Douglas fir on a rocky site on the east coast or centre of Vancouver Island oriented in a north to south direction will be windfirm. Sitka spruce in a fairly open stand, on well drained soils on the main stem of a stream can be considered reasonably windfirm.

The following steps are suggested in assessing an area for potential blowdown.

1. Using a map, assess the general geographical location and the orientation of a proposed leave strip for their exposure to storm winds.

2. Using a map, attempt to determine whether any humps, knolls, ridges or constrictions in the valley are present to funnel winds into a proposed leave strip.

3. On site consider the exposure to winds, the site factors such as soil depth and texture, tree species and rooting characteristics. Search for any indicators of a high blowdown likelihood such as hummocky micro topography, old blowdown, or skunk cabbage.

4. After the blowdown assessment has been made, consider the potential impacts of blowdown.

All of the factors outlined in this report have to be considered in an orderly fashion and balanced in order to assess the likelihood of blowdown. A table summarizing these factors is presented in the summary.

SUMMARY

Blowdown does not occur in all leave strips; neither does it occur randomly. It results from the interaction of a number of natural factors including location, local topography, climate, aspect and slope, soil depth and texture, tree species and rooting characteristics, and stream characteristics occurring simultaneously. It is also affected by the shape of the logged opening and the care exercised during and after logging. Because of this complexity, blowdown assessments can only be made relatively, in terms of a low or high probability of blowdown.

The probability of blowdown will be relatively low if the proposed leave strip is:	The probability of blowdown will be relatively high if the proposed leave strip is:
- on the east coast	- on the west or northeast coast
- inland rather than coastal or on a stream flowing into a coastal inlet that opens north, east or west	- on a coastal inlet opening southeast, south or southwest
- in mountainous terrain	- on coastal flats or steep or narrow valleys which funnel winds
- not exposed to winds over long openings, lakes or coastal flats	- exposed to winds particularly southerly storm winds
- protected by high ridges, firebreaks or timber on the opposite bank	- downwind of knolls, humps, shoulders, ridgetops or constrictions in valleys which cause winds to increase in speed and become more turbulent
- parallel to the direction of storm winds	- at right angles to storm winds or on a bend where a stream turns at right angles to the main valley

- in an area of low rainfall or with prolonged snow cover in winter	- in an area of high winter rainfall
- at the bottom, or well over the break, of a deep draw or a steeply sloped streamside	- along the top of a draw or steeply sloped streamside
- deep rooted or on deep well drained soils, shallow to bedrock soils where bedrock is fractured, or medium textured loamy soils where root development is not impeded	- shallow rooted or on poorly drained soils, shallow to bedrock soils over unfractured bedrock, very fine or very coarse textured soils or any soils where cemented, compacted or clay layers or stream gravels impede rooting
- predominantly Douglas fir, grand fir, western red cedar, Sitka spruce or deciduous trees	- predominantly western hemlock or amabilis fir
- an open grown stand where crowns have been exposed to wind	- a dense stand where trees and crowns have not been exposed to winds
- without wet site indicators such as skunk cabbage	- in wet or marshy areas with pockets of skunk cabbage
- in a young, healthy stand	- in a stand with evidence of root rot or other decay
- on a stream with stable streambanks and without bank undercutting	- on a stream with slumping or undercut streambanks
- in an area where little blowdown has occurred in adjacent leave strips or block perimeters	- in an area where blowdown has previously occurred in adjacent leave strips or block perimeters or where old blowdown is evident in the stand

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